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CHANDRAYAAN-2
LUNAR ORBITER & LANDER MISSION

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Abstract: Space Science and Interplanetary explorations are challenging missions that ISRO has been pursuing. Since the launch of India's first satellite Aryabhata, on 19th April 1975, Space Science exploration has been one of the main objectives of ISRO's Satellite Programme. Chandrayaan-1, India's First Mission to Moon (2008) proved ISRO's capability of building complex missions while the launch of Mars Orbiter Mission (2014) has proven India's prowess in Space. Chandrayaan-2 is the follow-on lunar mission after the successful Chandrayaan-1 mission, with indigenously developed Orbiter, Lander and Rover for Lunar exploration.

Keywords: Chandrayaan-2, Orbiter, Lander, Rover, IDSN, NGC, Altimeter

1. INTRODUCTION

Space science and interplanetary explorations are challenging missions which call for development of many new technologies. A mission to moon and other planets is the next logical step after realizing earth orbiting satellites. India has successfully progressed from the first experimental satellite Aryabhata to a moon mission Chandrayaan-1 in 2008 and a Mission to Mars (MOM) in 2014. Further exploration of the moon calls for Lander and Rover missions which forms the second phase of lunar exploration with Chandrayaan-2, wherein soft landing and roving in addition to in-situ measurements on moon along the traversed path will be carried out. With our launch vehicle GSLV-MII, a novel mission to moon consisting of an Orbiter, Lander and a Rover has been configured with the following mission objectives:

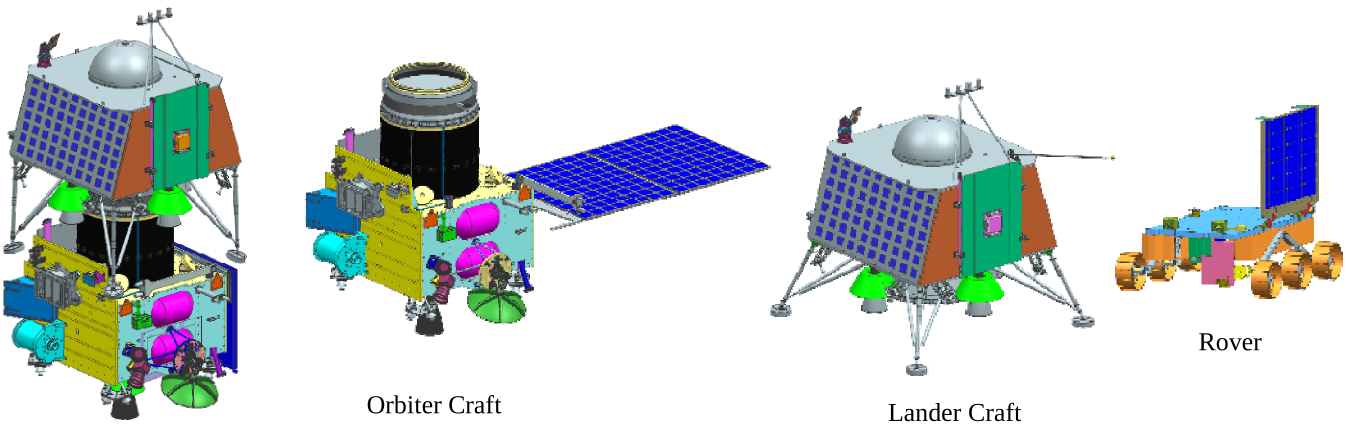
- Expanding the technologies inherited from Chandrayaan-1 Spacecraft and 'Develop and Demonstrate' newer technologies.

- Develop a Lunar Lander – Rover capable of soft landing at a specified location and deploy a Rover that will carry out in-situ analysis of soil.
- Carry payloads in Orbiter which will enhance the science derived from Chandrayaan-1.

The above mission objectives call for a number of new developments. The Lander has a gamut of technological challenges which upon successful development will be a stepping stone for future exploration missions to other planets. The Lander mission demands a suite of new sensors to achieve a safe and soft landing. The validation of these new technologies call for a number of innovative tests and the same has been carried out for Chandrayaan-2.

2. OVERVIEW

Chandrayaan-2, a composite module consisting of an Orbiter and Lander are interfaced mechanically through an inter-module adapter with a separation mechanism. This composite will be launched by GSLV-MII into a highly elliptical earth orbit. The orbiter maneuvers the composite to the lunar orbit by its propulsion system and once in the 100km lunar orbit at the identified time separates the lander. The lander follows the descent trajectory and after a short hovering phase at 100m for reconfirmation of the safe landing site lands at the identified site. Once the Lander has landed on the surface, the Rover is deployed and the Rover commences its journey on the moon surface. The Orbiter carries out science through the different payloads from the 100km orbit. The lander carries out experiments with its payloads at the landed site whereas the Rover moves around the area of interest in a semi-autonomous mode and carries out science at the determined sites.



Rover

Orbiter Craft

Lander Craft

Chandrayaan-2
Composite Module

Fig. 1. Chandrayaan-2 Mission Elements

2.1. Orbiter Craft

The Orbiter Craft is built around a cuboidal structure and houses the propulsion tanks and the separation mechanism of the launch vehicle at one end and lander at the other end. The Orbiter decks have the different housekeeping systems of the Spacecraft. The Solar array consists of two solar panels which are stowed in the launch configuration and deployed on separation in order to provide the power required for the Orbiter Craft during different phases around the earth and the moon. Lithium Ion battery provides the power support during eclipse and peak power requirements of the spacecraft. Orbiter is a three axis body stabilized spacecraft with reaction wheels which provide a stable platform for imaging. Thrusters are present for momentum dumping and attitude corrections. A bipropellant liquid engine is used to raise the orbit of the composite from earth parking orbit to 100km lunar orbit. The attitude and the orbit control electronics receive the attitude data from the star sensors and the body rates from the Gyro's for S/c control. The other sensors used for spacecraft control are Sun sensors and accelerometers. The telemetry system provides the health information of the spacecraft while the

tele-command system handles the command execution and distribution. The different payloads on the Orbiter are interfaced to the base band data handling system for formatting and further recording in solid state recorder for play back at a later time. The RF system consists of a S band TTC transponder and X band transmitter for Payload data transmission to Indian Deep Space Network (IDSN) station. The payload data is transmitted through a X-band dual gimbal antenna which will be pointed to the ground station.

2.2. Lander Craft

The Lander structure is a truncated pyramid around a cylinder which houses the propellant tank and the interface for the separation mechanism of Orbiter. The vertical panels have solar cells while the stiffener panels house all the electronic systems. The lander leg mechanism (Four nos.) provides stability upon landing on different terrains. The body mounted solar panels provide the power for the different systems during the mission in all phases. In addition, lithium ion battery supports the power requirements during eclipse and the lander descent. The Control electronics provide the interface to all the sensors and the actuator drives. The sensors are configured for inertial navigation from separation to the end of rough braking and the absolute sensors determine the position and velocity with respect to the landing site in order to guide the lander beyond the rough braking phase to the identified site. The lander Navigation guidance and control will be autonomous from separation onwards and has to ensure a precise, safe and soft landing on the lunar surface. The braking thrust for decelerating the lander is provided by four nos. of liquid engines. As it is required to have a controlled descent to the identified landing site the engines require throttlability. The attitude of the lander is maintained with eight nos. of thrusters. The TTC communication between the Lander – IDSN is in S band and the payload data is transmitted by a high torque dual gimbal antenna. The Lander has a TM-TC data handling system with inbuilt storage. The Rover is stowed in the lander during launch and upon landing the ramps are deployed and Rover starts its journey on the lunar surface. The other Lander payloads will be deployed on landing.

2.3. Rover

Rover is a six wheeled mobility system with the objective of performing mobility on the low gravity & vacuum of moon and in addition conduct science for understanding the lunar resources. Rover chassis houses all the electronics and has two navigation cameras to generate stereo images for path planning. The deployed solar panel provides the power during the mission. The rocker bogie mechanism along with the six wheels ensure a rugged mobility system over obstacles and slopes along the identified path for exploration of the region. The Rover communicates to the IDSN via the Lander. The two Rover payloads conduct science on the lunar surface.

3. MISSION

Chandrayaan-2 composite will be launched by GSLV-MII into a highly elliptical Orbit around the earth. The Orbiter propulsion system raises the orbit around the earth through a number of earth burn maneuvers and propels the composite to a Lunar transfer trajectory. Further, the Orbiter gets captured into a Moon orbit through a precise maneuver by the propulsion system of the Orbiter. Further, maneuvers around the moon are planned such that the orbital path of the composite in the 100 km circular orbit will be over the landing site at the identified day. The day of launch / day and position of insertion into the Lunar Orbit are to be timed so as to maximize the life of the Lander and Rover missions. This constraint will be met by proper planning of the Launch vehicle insertion parameters, orbit raising maneuvers and Lunar capture geometry with respect to Sun and Earth.

The Orbital parameter of the composite when around the moon will have to be precisely determined and corrections made so as to ensure that the composite is at the separation point at the pre-determined time. Once at this point, the Orbiter / Lander separation system will separate the two modules.

On separation, a deboost maneuver at 100km altitude, causes a free fall of lander to 18km altitude. Powered descent to the designated landing site is initiated using a closed loop Navigation, Guidance and Control system to ensure a precise soft landing at touchdown.

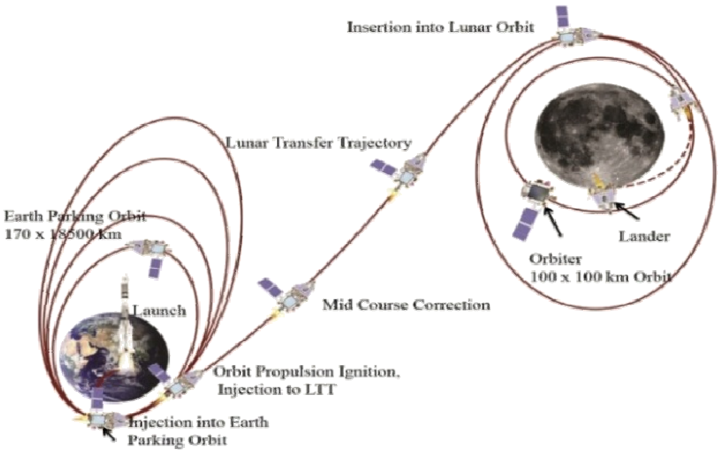


Fig. 2. Mission profile to Moon

Onboard Guidance Algorithm takes current position and velocity from Navigation (at every guidance cycle) and generates steering profile in real time by considering the end target states. The steering profile decides the magnitude of the thrust for each engine and the required attitude for the lander. The attitude controller tracks the reference attitude while ensuring closed loop stability.

Inertial Navigation is prone to errors due to factors such as error in initial states, propagation errors and inherent inaccuracies. This needs to be corrected with updates from Absolute Navigation sensors. When the lander is at a height of 7kms from moon's surface, the absolute position of the lander with respect to the landing site is determined using Lander position detection camera. In addition, at this instance the horizontal and vertical velocity, absolute height with respect to moon's surface are derived from the onboard instruments and provided to the closed loop Navigation Guidance and Control (NGC) system for further refinement of trajectory. This ensures a safe, soft and precise landing of the lander. The entire descent trajectory is as shown in the below figure.

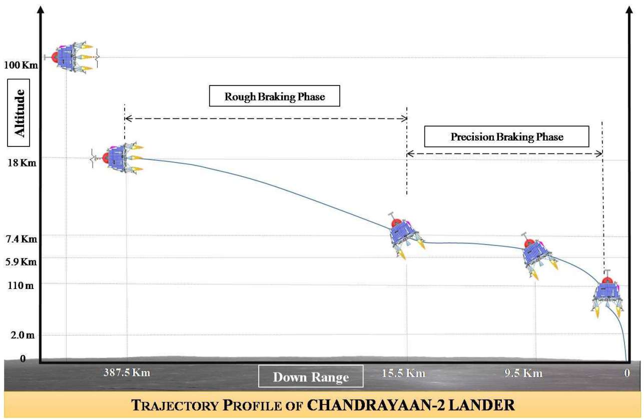


Fig. 3. Lander Descent Trajectory

The Lander Science payloads will carry out in-situ science on the Moon surface and transmit the data back to ground. Once on the moon surface, the Rover is deployed and the Rover performs mobility on the moon surface. The physical and mechanical properties of the regolith on the lunar terrain will have a bearing on the mobility of the Rover. The Navigation Sensors on the Rover aid in the semi-autonomous Navigation and tele-operation control. In addition to mobility, the Rover performs science experiments through its payload and the payload data is received on ground through the Lander. The Orbiter will continue to orbit around the Moon and will perform the science over the moon.

4. SCIENCE FROM CHANDRAYAAN-2

Chandrayaan-2 aims at understanding the origin and evolution of the Moon using instruments onboard Orbiter and in-situ analysis of lunar surface using instruments on the Lander and Rover. The instruments on the Orbiter and their science objectives are as follows.

- Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) along with Solar X-ray Monitor (XSM) will map the major elements on the lunar surface.
- L and S Band Synthetic Aperture Radar (SAR), will image the lunar surface to understand the scattering characteristics of surface and subsurface features including water ice in the Polar Regions.
- Imaging Infra-Red Spectrometer (IIRS) will image the lunar surface in the spectral range of 0.8 to 5.0 μm to investigate minerals and signatures of water and hydroxyl molecules.
- Terrain Mapping Camera (TMC-2) will provide a three-dimensional map of lunar surface.
- Neutral Mass Spectrometer (ChACE-2) will carry out detail study of lunar exosphere.

The instruments on the lander are as follows:

- Instrument for Lunar Seismic Activity (ILSA) which measures seismicity around the landing site.
- Chandra’s Surface Thermo physical Experiment (ChaSTE) will carry out the measurements of thermal properties of lunar surface.
- Radio Anatomy of Moon Bound Hypersensitive ionosphere and Atmosphere (RAMBHA-Langmuir Probe) will measure near surface plasma density and its diurnal changes.
- Dual Frequency Radio Science (DFRS) will measure the total electron content of lunar ionosphere.

The two payloads on the Rover are Laser Induced Breakdown Spectroscope (LIBS) and Alpha Particle X-ray Spectroscope (APXS) which carry out elemental analysis of the lunar surface around the landing site.

5. SELECTION OF LANDING SITE

The main factors that have been considered for arriving at the landing sites are:

- Maximize the Lander and Rover mission life w.r.t illumination and shadow movement in the landing and surrounding regions.
- Ensure availability of sufficiently large area for landing and mobility considering the probable error ellipse at the time of landing. The terrain at the site and the obstacles/ boulders to be considered from the point of view of Lander stability and Rover mobility.
- Ensure communication feasibility of lander to rover and lander to ground.

Data available from Chandrayaan-1 and other lunar missions have been utilized to arrive at the probable landing sites.

6. NEW TECHNOLOGIES IN THE LANDER MISSION

A Lander which has to demonstrate safe and soft landing calls for a number of new technologies and test/ simulation and the same has been taken up for this mission. The details of these are as follows:

6.1. Optimization of Mission and Descent Profile

The launcher lift-off mass and the propellant that can be loaded in the orbiter determine the initial injection orbit of the composite module. The Earth burn maneuvers and the lunar transfer trajectory have to be performed so as to optimize the propellant budget and also ensure that the composite is on the orbital path for separation at the identified date and time. The maneuver must take into account the ground station visibility and the eclipse period in earth orbit. Upon separation of lander, the descent profile to be followed has also to be optimized in view of Lander propellant budget constraints. The descent profile has to consider the mile stones to be met with respect to the sensor capabilities, accumulated error ellipses in view of initial orbit determination uncertainties, engine thrust variations, offsets and misalignments etc.

6.2. Braking Engines During Descent

In view of the absence of atmosphere on moon, active deceleration by thrusting will have to be adopted. In this mission, a bipropellant system with four 800N engines will be used. Eight 50N thrusters are used to ensure the required orientation during the entire phase of the descent. The error ellipse at separation (100km) which is due to composite state uncertainty, increases with time in view of the inertial navigation errors. To correct the same, at 7km it is required to have controllability in the engine thrust and the same is obtained by providing throttlability in all the four engines. This variability in the engine thrust ensures a safe and soft landing at the identified site irrespective of the accumulated errors at the end of rough braking phase.

6.3. Autonomous Navigation Guidance & Control

The Lander which will be travelling at 1.7 km/sec at 100km, on separation, will be de-orbited [by a Hohmann transfer] by firing its braking engines so as to reach a periapsis of 18 Km. The Lander module will be precisely navigated as per plan with the onboard Inertial Navigation System. Once at the periapsis the rough braking phase is initiated. During this powered descent phase the attitude of the Lander will be precisely controlled and the Navigation Guidance and Control System with the help of the Inertial sensors will provide the closed loop feedback for the actuator Systems. At the end of the rough braking phase [~7 km], the Hazard avoidance sensors will sense the position and velocity of the Lander with reference to the landing site. Based on the relative position and velocity with respect to the pre-determined landing site on the moon surface, the further trajectory is planned on board and the sensors along with actuators will guide the Lander to a position over the landing site [~100 m]. At this point, the Lander hovers over the site and the hazard avoidance sensor will determine the safest landing point in the near vicinity and the Lander will be maneuvered to this point. At a height of 2m, upon ensuring that the relative velocity with reference to moon surface is zero, the braking engines are cut off. The Lander freely falls to the surface and the landing leg mechanism will absorb the impact loads and ensure the integrity of the Lander for further operations. The entire operation from separation to touch down is fully autonomous and has to be performed by the onboard computers in the Lander without any intervention from ground.

6.4. Lander Sensors for Navigation

The inertial navigation of the lander is carried out by LIRAP (Laser gyro based Inertial Reference Unit and Accelerometer Package). The LIRAP consists of four ILG (ISRO Laser Gyro) and four CSA (Ceramic Servo Accelerometer) sensors. This sensor provides attitude referencing for the lander after it separates from the orbiter till landing. The accelerometers provide velocity increment for the liquid engine cutoff during orbit maneuvers. It also provides inertial navigation information (position, velocity & quaternions) from lander separation to touchdown.

One of the key elements essential for safe landing is the Hazard Detection and Avoidance (HDA) system. The HDA system comprises of several sensors like Orbiter High Resolution Camera (OHRC) for characterization of landing Site, Cameras for Horizontal velocity calculation, Camera for pattern matching and position estimation, Microwave and Laser altimeter, Laser Doppler velocimeter. All these sensors provide information like lander’s horizontal velocity, vertical velocity, height above moon’s surface, relative position of the lander w.r.t moon’s surface, hazard/safe zone around the landing site. The HDA system onboard the lander processes the inputs from the various sensors, compares the data collected with the information already stored in the lander and provides the required inputs to the Navigation and Guidance system in real time to correct the trajectory at the end of rough braking to enable a safe and soft landing.

6.5. Landing Leg Mechanism

The lander leg mechanism ensures that the energy at touch down is absorbed and all the lander systems are integral and stable for further conduct of payload deployments and science on moon. Four lander legs symmetrically placed are designed so as to withstand shocks on the uneven terrains / slopes in view of the lander terminal vertical and horizontal velocity. Each leg consists of a telescopic leg assembly with crushable damper material in the leg and foot pad. Extensive analysis and tests are done for the lander leg mechanism to ensure stability under extreme terrain conditions and terminal velocity.

6.6. Rover Mobility

Mobility of the Rover in the unknown lunar terrain is accomplished by a Rocker bogie suspension system driven by six wheels. Brushless DC motors are used to drive the wheels to move along the desired path and steering is accomplished by differential speed of the wheels. The wheels are designed after extensive modelling of the wheel-soil interaction, considering the lunar soil properties, sinkage and slippage results from a single wheel test bed. The Rover mobility has been tested in the Lunar test facility wherein the soil simulant, terrain and the gravity of moon are simulated. The limitations w.r.t slope, obstacles, pits in view of slippage/sinkage have been experimentally verified with the analysis results.

Fig. 4. Rover Mobility tests in simulated lunar facility

6.7. Semi-Autonomous Navigation of Rover

A pair of navigation cameras mounted on the Rover are capable of taking images of the moon's surface in front of the Rover. These images are sent to the ground control centre where the Digital Elevation Model of these images are created. Based on this data, the path in which the Rover can move is decided and the same is uplinked to the Rover (via lander). The slope that the Rover can navigate, the size of the boulder that the Rover can climb, the sinkage/ slippage are the basic inputs that are considered while planning the path for Rover movement. An inclinometer mounted on the chassis of the Rover computes the slope being navigated on the moon's surface and the same is used for safety reasons to terminate the motion in case the safe limits are exceeded. Other similar autonomous safety parameters like motor wheel current, communication feasibility with Lander and power generation from solar panel in view of shadows are monitored to ensure safety of the Rover during mobility.

6.8. Special Tests for Sensor, Actuator, Rover

All the lander sensors are being developed for this mission to assist the lander in identifying its current position, the attitude of the lander, its horizontal, vertical velocity, etc. The performances of all these sensors are

being verified in the Lander Sensors Performance Test. The sensors are mounted in an aircraft and measurements are carried out during the flight over simulated terrains at the intended heights and velocities. Other special tests which are being carried out are the Propulsion system static tests, Lander Actuator Performance Test, Rover mobility test, Lander leg mechanism performance tests etc. In the Lander Actuator Performance Test the integrated performance of the propulsion and NGC Systems are verified and demonstration of autonomous landing, hazard avoidance and a controlled vertical descent are demonstrated. The above tests are aimed to validate all the technologies that are required for a safe and soft landing at the identified site.

7. CONCLUSION

There has been a rebirth of lunar exploration across the globe and India is planning the same with Chandrayaan-2 mission. A number of new technology developments required for interplanetary missions carrying a Lander and Rover are being developed and demonstrated in Chandrayaan 2. The new technologies have to be thoroughly tested and this will call for novel simulation methods which are nearing completion. Presently Chandrayaan-2 Orbiter, Lander and Rover are in an advanced stage of realization.

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